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Preliminary Assessment of Perchlorate in Ecological Receptors at the Longhorn Army Ammunition Plant (LHAAP), Karnack, Texas

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Abstract. There have been increasing human health and ecological concerns about ionic perchlorate (ClO_4^-) since it was detected in drinking water sources in 1997. Perchlorate is known to affect thyroid function, causing subsequent hormone disruption and potential perturbations of metabolic activities. According to current estimates, perchlorate is found in the surface or groundwater of 14 states, including Texas. Longhorn Army Ammunition Plant, located in east central Texas, was a facility historically associated with perchlorate-containing propellants and rocket motors. Subsequently, perchlorate contamination in ground and surface waters at the facility has been reported. Soil, sediment, water, vegetation, and animal tissue samples were collected from several locations within the plant for a preliminary site assessment of perchlorate contamination. Perchlorate concentrations ranged from 555–5,557,000 ppb in vegetation, 811–2038 ppb in aquatic insects, below detection limits (ND) to 207 ppb in fish, ND-580 ppb in frogs, and ND–2328 ppb in mammals.

Consistent with our hypothesis, aquatic organisms inhabiting perchlorate-contaminated surface water bodies contained detectable concentrations of perchlorate. Additionally, terrestrial organisms were exposed through pathways not necessarily related to contaminated surface waters. Therefore, these data demonstrate that aquatic and terrestrial species are exposed to perchlorate in the environment. To our knowledge, this represents the first incidence of perchlorate exposure among wild animals reported in the scientific literature.

Keywords: perchlorate; Longhorn Army Ammunition Plant; body burden; ecological receptor; fish; amphibians; mammals; wildlife; plants

Introduction

The perchlorate anion (ClO_4^-) has gained a great deal of attention from toxicologists, regulators, and the general public of late. Recent advances in analytical capabilities (Dionex, 1998) have allowed for improved detection of the perchlorate anion in water. Utilization of these improved analytical capabilities has produced data suggesting more widespread contamination of ground and surface water with perchlorate, especially in areas of the western U.S. (Urbansky, 1998). These data also suggested that environmental contamination of water sources usually occurs near military and industrial installations where perchlorate is handled (Urbansky, 1998), although it has also been detected

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in certain fertilizers (Susarla et al., 1999a). Perchlorate (as ammonium perchlorate) is a powerful oxidizer used routinely in propellants and explosives. Perchlorate is included in aerospace materials (rocket propellants) as well as commercially available products (e.g., road flares, fireworks, airbags).

In aqueous systems, the perchlorate anion readily disassociates from its various cationic ligands, such as ammonium, and remains stable for long periods under normal environmental conditions (Urbansky, 1998). Solubilized perchlorate moves rapidly through environmental media and can be readily transported through runoff.

The major health concern for perchlorate is the interference with normal thyroid function. A wealth of human health data indicate that perchlorate competitively inhibits iodide uptake into the thyroid gland via a sodium-iodide transporter, resulting in reduced excretion of thyroid hormones followed by a feedback loop-induced increase in secretion of thyroid stimulating hormone (Saito et al., 1983). Perchlorate has been used in the phamacotherapeutic treatment of Graves disease due to its prototypical thyroid inhibitory properties (Orgiassi and Mornex, 1990). Thyroid hormones have many roles in vertebrate physiology, including involvement in regulation of embryonic growth and development. For these reasons, and because perchlorate has been detected in drinking water in several areas throughout the United States, concerns have been raised over the potential for adverse human health effects in populations chronically exposed through drinking water (Li et al., 2000; Lamm and Doemland, 1999).

In contrast to the wealth of human health data, little data exist on potential ecological exposure and potential effects from environmental perchlorate contamination. Fish and wildlife are also likely to be exposed to perchlorate in areas where such contamination exists. Because thyroid hormones play homologous roles in fish and wildlife as in humans, there exists the potential for disruption of endocrine homeostasis in these species as well (Kendall et al., 1998). Such effects could ultimately be manifested at the population, community, or ecosystem level of biological organization.

Evaluating tissue levels and identifying possible sources of perchlorate contamination are critical in determining toxicological and ecological exposure. However, the unique chemical characteristics of this anion make accurate quantitation of perchlorate concentrations in biological matrices difficult. The presence of additional ions, proteins, lipids, and other biomolecules that can foul ion exchange columns further confounds accurate determination of perchlorate concentrations in biological tissues and fluids. Perchlorate uptake and bioconcentration in plant matter has been documented (see Susarla et al., 1999b; Nzengung et al., 1999; Ellington and Evans, 2000), but such is not the case for animal tissues except for laboratory studies (Wolff, 1998). To our knowledge, there are no literature reports of perchlorate concentrations in tissues of animals exposed to perchlorate in the environment.

Based on the high water solubility of perchlorate, aquatic organisms and organisms at the aquatic-terrestrial interface would theoretically receive the highest exposure. Using analytical methods developed in our laboratory (Anderson and Wu, 2001), we evaluated tissue concentrations of perchlorate in a number of potential receptor organisms inhabiting a site in east Texas where certain areas are contaminated with ammonium perchlorate. Our objective in this paper was to evaluate the usefulness of new analytical techniques and methods in quantifying perchlorate exposure among potential ecological receptors. Here we report our preliminary assessment of perchlorate concentrations in environmental compartments and tissues of various ecological receptors at the Longhorn Army Ammunition Plant, Karnack, Texas.

Methods

Study site

Longhorn Army Ammunition Plant (LHAAP), listed on the US EPA National Priorities List, was the study site chosen for this preliminary assessment (Fig. 1). The LHAAP (approximately 8500 acres) is in the Caddo Lake watershed. Caddo Lake is located in Marion and Harrison Counties in east Texas and Caddo Parish in northwest Louisiana. Numerous military activities at the LHAAP (primarily manufacturing solid propellant rocket motors, and rocket demilitarization pursuant to the Intermediate-range Nuclear Forces (INF) treaty) resulted in areas contaminated with ammonium perchlorate. Several locations within LHAAP have been associated with perchlorate handling including a perchlorate grinding facility (Building 25C), two separate burning grounds, and a water treatment holding

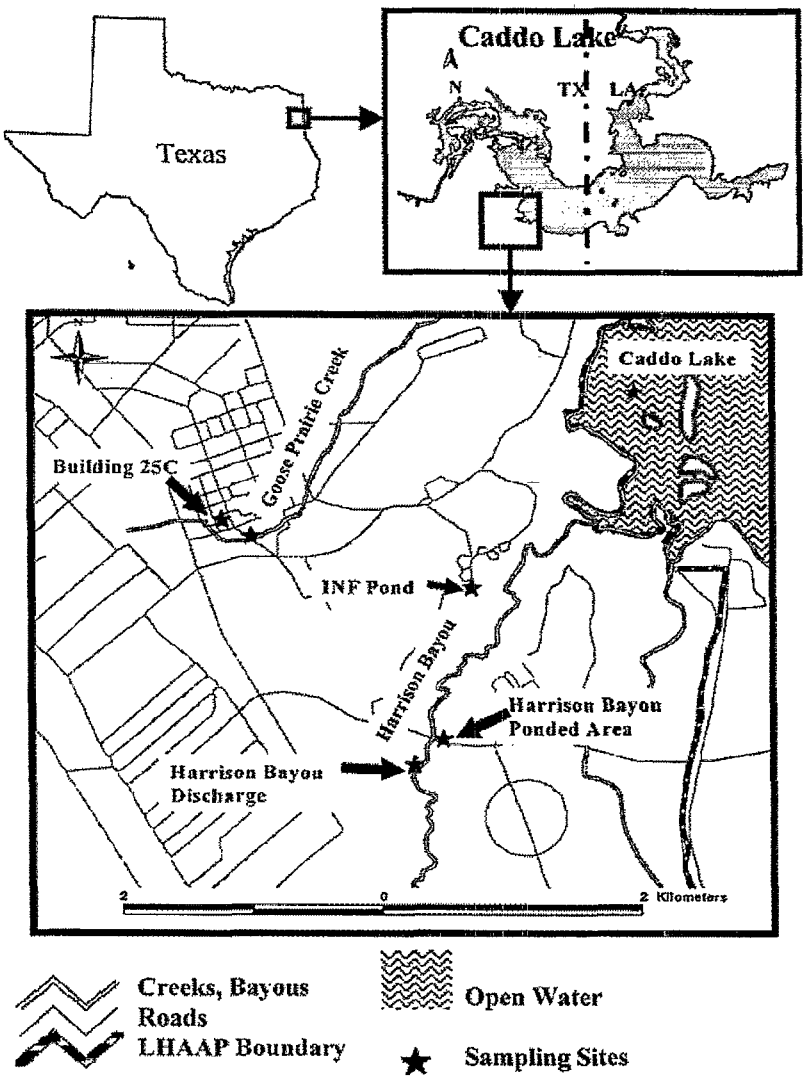

Figure 1. Map of Longhorn Army Ammunition Plant (LHAAP) and the surrounding area indicating where environmental samples were collected for perchlorate analysis.

pond (INF Pond). Ecologically sensitive wetland habitats including the Harrison Bayou drainage system, Goose Prairie Creek, Central Creek, and Caddo Lake surround these areas and are potentially exposed to perchlorate contamination through runoff, erosion, and groundwater movement. In fact, analytical evaluation of ground and surface water, soil, and sediment samples has indicated that perchlorate contamination at LHAAP is potentially bioavailable to both aquatic and terrestrial organisms.

To conclude decommissioning, remedial activities at LHAAP have included primarily the interception

and treatment of shallow groundwater for volatile organics with air stripping and carbon polishing, and precipitation of metals. Perchlorate in the groundwater is not removed by the current treatment procedures at LHAAP as the current remedial activities were implemented as Interim Remedial Actions at a time prior to identification of perchlorate as a regulated contaminant or contaminant of concern. Therefore, the existing groundwater treatment plant was not designed for treatment of perchlorate.

Subsequent to treatment, groundwater is discharged to Harrison Bayou, but only when water is actively flowing downstream. When there is no flow in Harrison Bayou (e.g., during dry conditions), the treated groundwater is pumped to the INF holding pond for storage until flow in the bayou resumes. Thus, depending on the conditions, treated water containing perchlorate may or may not be discharged to Harrison Bayou. It should be noted that a fluidized bed reactor was installed in early 2001 for the purpose of removing perchlorate from the treated water prior to discharge into Harrison Bayou.

During the period (31 October to 8 November, 1999) in which water, sediment and animal samples for this preliminary assessment were collected, treated water containing perchlorate was only discharged into Harrison Bayou on 3 days (1–3 November). Soil samples were collected from Building 25C in January 2000, and vegetation samples were collected from the INF Pond and Building 25C on 13 September and 20 October 2000, respectively. In this context, we present the following analytical determinations of perchlorate concentrations, particularly those associated with Harrison Bayou.

Water, sediment, soil, and vegetation collection

Water samples were collected in precleaned 60 ml glass vials (Wheaton, Millville NJ) from just below the water surface. Sediment was collected by scooping a sample from the upper 2 cm (approx.) of the bedded sediment into identical glass vials. All water samples (5 ml) were filtered (0.45 μm) and either (1) analyzed for perchlorate ion directly, or (2) diluted with distilled, deionized water (18 MΩ) and then analyzed. Perchlorate in sediment samples was determined by analyzing the sediment pore water. Pore water was collected by allowing the sediment to settle and pipetting a sample of pore water from the top.

Soil samples were taken from the top 15 cm using a precleaned trowel. Soil samples were weighed, placed in glass jars, and extracted (mechanical agitation) with distilled, deionized water (18 MΩ; 2 : 1 water : soil). Water extracts were filtered (0.45 μm) and either (1) analyzed for perchlorate ion directly, or (2) diluted with distilled, deionized water (18 MΩ) and then analyzed.

Vegetation samples were collected from areas of known perchlorate contamination adjacent to areas where animals were collected, including Building 25C, and the INF Pond. Vegetation samples were removed from soil or sediment and placed in plastic bags. Prior to extraction, vegetation samples were divided (seeds, stems, leaves, etc.), air-dried, and weighed.

Animal collection

Tadpoles and aquatic damselfly (*Odonata*) larvae were collected with dip nets. Fish were collected with dip nets or seines, except for largemouth bass (*Micropterus salmoides*), which were collected from Caddo Lake by electrofishing. Fish were collected from Harrison Bayou in the stretch between the Harrison Bayou Discharge and Harrison Bayou Ponded Area (Fig. 1). Adult amphibians were collected by hand. Small mammals were collected using Sherman live traps baited with birdseed and peanut butter. All animal collections were done between 31 October and 8 November,1999.

Reagents and standards

All perchlorate calibration standards were prepared from a 100 μg/ml certified sodium perchlorate standard (AccuStandard, Inc., New Haven, CT) in distilled, deionized, water (18 MΩ). Sodium hydroxide (eluent) was purchased from Fisher Scientific and diluted with distilled, deionized, water (18 MΩ) to the appropriate concentration for the ion chromatography method (100 mM).

Tissue samples

Tissue samples were either composited or extracted individually, depending on the size of the sample. Tissue composites were constructed using species and location as the primary criteria. Samples (individual tissues or composites) were weighed, air-dried, and extracted with distilled, deionized, water (18 MΩ) using an Accelerated Solvent Extractor (ASE 200, Dionex Corp.). The extraction method (Anderson and Wu, 2001) was developed using

perchlorate-perfused bovine tissue (kidney). Briefly, samples were placed inside 22 ml extraction cells, heated for 5 minutes at 100 °C, filled with distilled, deionized water, and pressurized to 1500 psi. Total extraction time was 15 minutes. At extraction completion, extract volume was recorded.

Tissue extract cleanup

Tissue extracts were cleaned prior to analysis using solid phase extraction (SPE). A variety of SPE cartridges and ion exchange membranes were evaluated during the development of the tissue extraction procedure (Anderson and Wu, 2001). Ultimately, strong cation exchange (SCX) cartridges were selected based on accuracy and reproducibility. The SCX cartridges were conditioned using (sequentially) distilled, deionized, water, 3 mM HCl, and distilled, deionized, water. Extracts (1 ml) were passed through the SCX cartridge followed by 4 ml of distilled, deionized, water. Eluates were collected, filtered (0.45 μm), and analyzed as described below.

Analysis

Analysis of perchlorate ion was carried out using a Dionex DX-500 Ion Chromatography System equipped with a GP50 gradient pump, a CD20 conductivity detector, and an AS40 automated sampler (Dionex Corp.). PeakNet® chromatography software was used to control the system. Ion separation was made with a Dionex IonPac AS16 (250 mm × 4.0 mm) analytical column. Conditions for the system were as follows: runtime = 12:00 min; flow rate = 1.0 ml/min; eluent = 100 mM sodium hydroxide; injection volume = 1000 μl. Ion detection was by suppressed conductivity in the external water mode. A five-point standard curve was constructed from constant volume injections of calibration standards of 2.5, 5, 10, 20, and 100 ppb (ng/ml). Computer-generated peak areas were used to measure sample concentrations in an external standard mode. Using the analytical method described above, the detection limit for perchlorate anion in water was 1 ppb (ng/ml).

Results and Discussion

This preliminary assessment of perchlorate in ecological receptors inhabiting the LHAAP includes residue data from water, sediment, soil, vegetation, and biota (Table 1). Due to the nature of some sites at LHAAP included in this preliminary assessment, not all environmental matrices are applicable. For example, since the Building 25C area does not have "surface water" or "sediment", no data are reported for those matrices. In addition, we have reported perchlorate concentrations in the surface water and sediment only when biota were also collected (with the exception of Central Creek). A further assessment of perchlorate in water and sediment (spatial and temporal) at LHAAP will be presented in a subsequent ecological risk assessment paper.

Water, sediments, soil, and vegetation

Perchlorate was detected in water and/or sediment, and soil samples from all the selected sites sampled at LHAAP (Fig. 1, Table 1). With the exception of samples from the INF Pond, perchlorate concentrations in all water, sediment, and soil samples were less than 85 ppb (ng/ml). Perchlorate concentrations in water from the INF Pond during this initial assessment ranged from 30 to 31 ppm (μg/ml); Perchlorate concentrations in INF Pond sediment pore water ranged from 12 to 35 ppm (μg/ml).

Based on some of the preliminary data, we collected additional samples of vegetation from LHAAP. Bullrushes (*Scirpus* sp.) growing out of the INF Pond were found to contain perchlorate at concentrations of 7620 (± 1460), 4450 (± 2240), and 840 (± 410) ppb (dry weight, ng/g) in above waterline tissues, below waterline tissues, and roots, respectively.

Crabgrass (*Digitaria* sp.), cupgrass (*Erichloa* sp.), and goldenrod (*Solidago* sp.) samples collected from areas adjacent to Building 25C contained extremely high concentrations of perchlorate in blades or leaves (Table 1). Perchlorate concentrations were highest in goldenrod leaves compared to seeds, stems, and roots (Table 1). These results are similar to those seen by Nzengung et al. (1999) using willow trees (*Salix nigra*) where most of the perchlorate accumulated in leaves. Perchlorate was also detected in seeds from both goldenrod and crabgrass at concentrations of 184 and 1880 ppm (μg/g), respectively.

Based on these findings, it was evident that terrestrial wildlife inhabiting LHAAP could become exposed to perchlorate through ingestion of water, soil, sediment, and vegetation.

Table 1. Concentrations (ppb) of perchlorate in ecological receptors collected at the Longhorn Army Ammunition Plant, Karnack, Texas. All samples were collected November, 1999 unless stated otherwise.

Site	Matrix/Species	N(N Detects)	Detected Conc. (ppb)	Comments
Harrison Bayou Discharge	Water	3(1)	4	
	Sediment	3(0)	—	
	Green tree frog	1(1)	86	Composite of a single liver, kidney, carcass, and 2 whole frogs
	Harvest mouse	1(0)	—	Composite of 5 livers
	Cotton mouse	2(1)	356	Composites of 5 livers each
Harrison Bayou Ponded Area	*Notropis* spp.	2(1)	77	Composites of approximately 10 fish each
	Weed shiner	3(1)	100	Composites of approximately 3, 6, and 8 fish each
	Mosquitofish	1(1)	206	Composite of 7 fish
	Juvenile Sunfish	1(1)	132	Composite of 2 fish
	Northern cricket frog	1(0)	—	Composite of 6 whole frogs
	Green tree frog	1(1)	153	Composite of 2 livers, 2 kidneys, and a single adrenal
	American toad	1(0)	—	Composite of 2 kidneys, 2 livers, carcass, testes, and adrenal
	Bullfrog	2(0)	—	Composites of livers and kidneys from 4 frogs
Goose Prairie Creek	Water	3(3)	44, 81, 85	
	Sediment	3(1)	78	
	Mosquitofish	2(2)	83, 131	Composites of approx. 7 fish each
	Notropis spp.	1(0)	—	Composite of 5 fish
	Blackstripe top minnow	2(1)	104	Composites of approx. 5 fish each
INF Pond	Water	3(3)	30,776, 31,370, 31,438	
	Sediment	3(3)	12,185, 27,704, 35,630	
	*Bullrush (above waterline)	4(4)	5975, 7211, 7816, 9487	Dry weight basis
	*Bullrush (below waterline)	4(4)	2422, 3118, 4806, 7459	Dry weight basis
	*Bullrush (roots)	2(2)	555, 1133	Dry weight basis
	Damselfly larvae	3(3)	811, 1753, 2038	Composites of 6 damselflies each
	Bullfrog tadpoles	3(3)	1130, 1277, 2567	
	Chorus frog	1(1)	580	1 whole frog
Building 25C	**Soil	18(4)	50, 174, 249, 322	Soil depth 0–6 inches
	***Crabgrass (seeds)	1(1)	1,880,000	Dry weight basis
	***Crabgrass (blades)	1(1)	5,557,000	Dry weight basis
	***Cupgrass (blades)	1(1)	1,060,000	Dry weight basis
	***Goldenrod (seeds)	1(1)	184,000	Dry weight basis
	***Goldenrod (leaves)	1(1)	1,030,000	Dry weight basis
	***Goldenrod (stems)	1(1)	6000	Dry weight basis
	***Goldenrod (roots)	1(1)	14,000	Dry weight basis
	Southern short-tailed shrew	1(0)	—	Liver
	Harvest mouse	2(2)	1120, 2328	Composites of approximately 8 livers each
	Cotton mouse	1(0)	—	Composite of 3 livers
Central Creek	Water	3(1)	8	
	Sediment	3(0)	—	
Caddo Lake	Largemouth bass	5(0)	—	Composites of 4 liver samples each
	Largemouth bass	6(0)	—	Composites of muscle tissue; trace amounts found in 2 samples
	Northern cricket frog	1(0)	—	Composite of 3 whole frogs

Table 2. (Continued)

Site	Matrix/Species	N(N Detects)	Detected Conc. (ppb)	Comments
Miscellaneous	Small mammal thyroid	1(1)	589	Composite made up of thyroids from 7 *R. fluvescens* (admin bldg—3 samples; bldg 25C—4 samples), 5 *Peromyscus* (Harrison Bayou Treatment Plant Discharge—4 samples; Bldg 25C—1 sample), and one *Sigmodon* from the Burning Grounds
Miscellaneous	Small mammal thyroid	1(1)	2170	Composite made up of thyroids from 9 *R. fluvescens* (bldg 25C—8 samples; admin bldg—1 sample), 5 *Peromyscus* (Harrison Bayou Discharge—5 samples), and two *Sigmodon* from the burning grounds

FISHES—Red shiner (*Cyprinella lutrensis*), Mosquitofish (*Gabusia affinis*), Bluegill sunfish (*Lepomis macrochironis*), Largemouth bass (*Micropterus salmoides*), Blackstripe topminnow (*Fundulus notatus*), Ironcolor shiner (*Notropis chalybaeus*), Weed shiner (*Notropis texanus*).
FROGS—Green tree frog (*Hyla cinerea*), Northern cricket frog (*Acris crepitans crepitans*), American toad (*Bufo americanus*), Bullfrog (*Rana catesbiena*).
MAMMALS—Cotton mouse (*Peromyscus gossypinus*), Harvest mouse (*Reithrodontomys fulvescens*), Southern short-tailed shrew (*Blarina carolinensis*), Cotton rat (*Sigmodon hispidus*).
INSECTS—Damselflies (order *Odontata*).
PLANTS—Bullrush (*Scirpus* sp.), Crabgrass (*Digitaria* sp.), Cupgrass (*Erichloa* sp.), Goldenrod (*Solidago* sp.).
ND = not detected.
*Collected 13 September 2000.
**Collected January 2000.
***Collected 20 October 2000.

Fish and amphibians

Perchlorate was found in tissues of several species of fish, amphibians, and aquatic insect larvae at LHAAP. In general, fish species were small omnivores or invertebrivores. Because the perchlorate anion is highly soluble in water, a likely route of exposure in aquatic species is through respiratory surfaces. Highly water-soluble substances like perchlorate generally do not bioconcentrate in biota (Rand, 1995), and perchlorate bioconcentration was not evident in samples acquired from LHAAP. For example, bullfrog tadpoles and damselfly larvae collected from the INF Pond had far lower concentrations of perchlorate than was present in water, although the body burdens were comparable between the two taxa. In Goose Prairie Creek, the concentration of perchlorate tended to be slightly higher in fish tissue than in the water, but it was not possible to collect enough samples to determine if this difference was statistically significant. In contrast, fish and frogs from Harrison Bayou discharge had far greater levels of perchlorate than was found in the water (Table 1). In fact, for two of the Harrison Bayou discharge water samples, the levels of perchlorate were below detection limits, while a third showed levels of perchlorate that was at least 20 times lower than that found in fish tissue.

It should be noted that the three sites have dissimilar perchlorate sources, which may contribute to differences in patterns of exposure among biota. Treated groundwater containing perchlorate is discharged to Harrison Bayou when water is actively flowing downstream, but stored in the INF holding Pond when flow is not sufficient in the bayou. In Goose Prairie Creek, the presence of perchlorate is probably attributable to runoff from and/or percolation through contaminated soils around Building 25C. In the Harrison Bayou discharge area, on the other hand, water containing perchlorate is discharged into surface water, where it is diluted with natural surface waters within the bayou. Because treated ground water was only pumped into the bayou when there was sufficient natural flow, input of perchlorate was intermittent or sporadic, depending on the amount of rainfall feeding Harrison Bayou. In fact, data collected from Harrison Bayou at different times

indicate that perchlorate is only detectable in the bayou when ground water is being discharged (unpublished data), suggesting that perchlorate rapidly dissipates in this stream. Treated water from the treatment facility was pumped into Harrison Bayou (1 through 3 November, 1999) during sample collection. The biota and water samples from Harrison Bayou were collected when groundwater was not being discharged, which explains the low water concentrations. However, the trend towards elevated concentrations of perchlorate in fish and frogs suggests that perchlorate is more persistent in fish and amphibians than in these aquatic systems. This indicates that exposure of indigenous fish and wildlife to perchlorate may not be adequately assessed by simply measuring water concentrations.

Mammals

Diverse small and medium-sized mammalian species were also collected from LHAAP for perchlorate analysis. Mammal collection sites did not correspond completely to water, sediment, and aquatic species collection sites, but included other areas of known perchlorate contamination. Rodents were collected near (within 100 m) the Harrison Bayou discharge area, and livers were analyzed for perchlorate content. We examined rodent liver tissues for perchlorate based on findings from earlier unpublished studies with laboratory-dosed rodents (data on file). Additionally, livers are relatively large tissues in rodents permitting sufficient sample size for analysis. A composite liver sample from cotton mice (*Peromyscus gossypinus*) captured at the Harrison Bayou discharge area contained perchlorate at 356 ppb, but additional composites of livers from cotton mice and harvest mice (*Reithrodontomys fulvescens*) caught in this area contained no detectable concentrations of perchlorate. Cotton mice are omnivorous, consuming invertebrates and some seeds (Choate et al., 1994).

Rodents were also collected near (within 50 m) Building 25C at LHAAP. This building was historically used for grinding raw ammonium perchlorate. Soil samples, collected subsequent to rodent collections, later confirmed the presence of perchlorate around the perimeter of this building, and vegetation samples collected near the building contained extremely high concentrations of perchlorate (Table 1). Two composite liver samples from harvest mice collected from this area contained 1120 and 2328 ppb perchlorate. Seeds and invertebrates make up the major portion of the diet of harvest mice, but they also consume grasses and herbs (Choate et al., 1994). Yet a single cotton mouse liver composite from this site contained no detectable perchlorate concentration. A single southern short-tailed shrew (*Blarina carolinensis*) collected at Building 25C, contained no detectable concentration of perchlorate.

Composite samples consisting of thyroid tissue from harvest mice, cotton mice, and cotton rats (*Sigmodon hispidus*) captured at the Harrison Bayou discharge area and other sites within LHAAP contained perchlorate concentrations ranging from 589 to 2170 ppb. Detection of perchlorate in thyroid tissues would be expected based on the well-documented thyroid-specific mechanism of action. Other mammals examined for perchlorate exposure at LHAAP included a single raccoon (*Procyon lotor*), and a nine-banded armadillo (*Dasypus novemcinctus*), neither of which contained detectable concentrations of perchlorate in liver tissues. Thyroid tissues from these animals were not analyzed for perchlorate contamination.

Two species of rodents, with similar natural history characteristics, were collected at two sites where perchlorate was detected. No species-specific exposure patterns were evident in this limited assessment. However, these data demonstrate that terrestrial organisms, including mammals, can be exposed to perchlorate from contaminated soils, contaminated surface waters, and through ingestion of contaminated vegetation. High concentrations of perchlorate in seeds of plants at Building 25C could contribute significantly to exposure among granivorous invertebrate, avian, and mammalian species. Because few rodents are completely dependent on surface water supplies to satisfy drinking requirements, ingestion of soil may also be a major source of contaminant exposure among wildlife (Beyer et al., 1994). For example, rodents might be exposed to perchlorate through direct ingestion of soil and through food items such as terrestrial and aquatic invertebrates, or vegetation and seeds grown in perchlorate-contaminated soil or irrigated with perchlorate-contaminated water.

Although sample sizes were small, this preliminary assessment of organisms inhabiting a contaminated site demonstrates that perchlorate exposure does occur among a number of disparate species and taxa. Exposure occurred among strictly aquatic organisms, semi-aquatic species, and terrestrial species. Future studies will include assessment of exposure among

other receptors, exposure dynamics, and assessment of potential perchlorate-related effects at the individual (thyroid function, growth, reproduction), population (population dynamics, demography) and community (community structure, predator–prey dynamics) levels of biological organization.

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